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Title: Influences of Forest Management Practices on Cavity Resources in Mixed Deciduous Forest in Thailand

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W. Daniel Edge

Effects of single-tree selection systems on tree cavity abundance have not been studied in Thailand. Although logging has been banned since 1989, it may resume in the future after forests recover, or because of the high demand for wood products. Mixed deciduous forests are an important potential timber resource in the country.

I compared tree and cavity densities in unlogged and logged mixed deciduous forest (5 stands in each type) in Huai Kha Khaeng Wildlife Sanctuary in western Thailand. Number of cavities/tree, diameter at breast height (dbh), and conditions of tree tops were recorded for 3,142 trees of 91 species ≥20 cm dbh. Tree heights and decay classes were recorded for 1,324 cavity trees. Tree densities (t = 2.89, 8 df, P < 0.0199), cavity tree densities (t = 4.27, 8 df, P < 0.0027), and cavity densities (t = 4.44, 8 df,

$\underline{P} < 0.0044$) were greater in unlogged than in logged stands. Ninety-two percent of cavity trees were alive; dead trees were uncommon, probably because of annual ground fires.

Alangium salviifolium, *Lagerstroemia* spp., and *Vitex* spp. were the taxa most likely to form cavities. They accounted for 50% of all trees and 66% of the cavities in unlogged habitats. Logging did not affect tree densities of these species nor cavity densities of *Lagerstroemia* spp. and *Vitex* spp. However, logging reduced *Alangium salviifolium* cavity densities.

Condition of tops, dbh, and decay classes 2, 3, and 4 were associated with the number of cavities/cavity tree for all species combined. Only dbh was important for the dominant species. Average dbh of cavity trees in unlogged stands for all species combined ($\bar{x} = 46$ cm) was larger ($\underline{t} = -7.56$, 8 df, $\underline{P} < 0.0001$) than for noncavity trees ($\bar{x} = 34$). Cavity trees were larger in diameter ($\underline{t} \leq -3.42$, 8 df, $\underline{P} < 0.0111$) than noncavity trees for the dominant species.

Single-tree selection cutting reduced cavity abundances in this mixed deciduous forest. Maintenance of cavity-forming species and leaving more large-diameter trees may be required to maintain habitat for cavity-dependent wildlife.

Influences of Forest Management Practices on Cavity Resources in Mixed Deciduous Forest in Thailand

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Assistant Professor of Fisheries and Wildlife in charge of major

Redacted for Privacy

Head of Department of Fisheries and Wildlife

Redacted for Privacy

Dean of Graduate School

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Typed by researcher for Anak Pattanavibool

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

INFLUENCES OF FOREST MANAGEMENT PRACTICES ON CAVITY RESOURCES IN MIXED DECIDUOUS FOREST IN THAILAND

INTRODUCTION

Cavities in trees are an important resource for wildlife; wildlife use cavities as nesting and resting sites, and potentially as feeding sites (Scott et al. 1978, McComb and Noble 1982). Birds are the dominant cavity users, followed by mammals and some amphibians and reptiles (Hunter 1990:162). Birds nesting in cavities usually comprise 30-45% of forest bird communities (Scott et al. 1980). In addition, invertebrates that are an important food source for wildlife (Conner et al. 1975) often occupy cavities (McComb and Noble 1982). Populations of cavity-nesting birds may be limited by the availability of cavities (Hamerstrom et al. 1973, Holeroyd 1975, Dahlsten and Copper 1979, Cody 1985).

Despite the importance of tree cavities to wildlife, little is known about the distribution and abundance of trees that contain cavities or the decayed wood substrate for cavity-excavating wildlife. Most research has focused on management of cavity nesters and considered the types of snags used for nesting, and correlations between snags and breeding bird densities (Conner and Adkinson 1977; Scott 1978, 1979; McComb et al. 1986a). Dead tree densities and characteristics probably vary among forest types, stand ages, and stand histories (McComb et al. 1986a). Site characteristics such as slope, distances from natural openings, and distances from water also may affect dead tree densities (Morrison et al. 1986).

Intensive silvicultural practices may adversely affect cavity-dependent wildlife (Conner et al. 1975, Hardin and Evans 1977, Bull 1978, Thomas et al. 1979, McComb and Noble 1980). Shortages of potential cavity nest sites may exist in young forests (Flack 1976) and in all ages of intensively managed forests (McClelland 1977, Carey 1983). Unmanaged timber stands usually have higher densities of snags than managed stands (Cline et al. 1980).

Significance of cavity resources and effects of timber management have been documented for North American habitats, but these relationships are poorly documented for tropical forests. Available data indicate that cavities may be important components of tropical forests. In India, decades of European forestry practices have created large plantations with few snags, little downed wood, and low floral and structural diversity, and have caused declines in many wildlife species, including many cavity-nesting birds and mammals (Marcot 1992). In Venezuela, parrots are threatened primarily by habitat destruction that is causing loss of nest cavities (Beissinger and Bucher 1992). Timber management in Victoria, Australia, removed eucalypt (Eucalyptus spp.) cull trees that provided nesting hollows and dwellings for many species of native birds and mammals (Cowley 1971). Poonswad and Tsuyi (1989) concluded that 5 species of cavity-nesting hornbills in Thailand were vulnerable to logging because they nested in large tracts of pristine forest.

In Thailand, the mixed deciduous forest type covers approximately 33,900 km^2 or 22% of the total forested area of the country (Thailand Royal Forest Department 1991), and was an important source of timber until 1989, when logging was banned (Dumrongthai 1990). The impacts of logging on cavity resources in this forest type have not been studied, and logging is likely to resume in this forest type in the future. Information on the effects of logging on cavity resources will be needed to manage wildlife habitat when logging resumes. I determined cavity availability in mixed deciduous forests in Huai Kha Khaeng Wildlife Sanctuary in unlogged and logged areas. Specifically, I (1) determined the tree species most likely to form cavities in logged and unlogged areas; (2) determined which factors (height, diameter at breast height [dbh], and decay class) were related to cavity abundance; and (3) compared cavity densities between logged and unlogged forests.

STUDY AREA

The study was conducted in Huai Kha Khaeng Wildlife Sanctuary (HKKWS), a 2,574-km^2 reserve in Utai Tani Province of western Thailand (Fig. 1). HKKWS has a diverse flora and fauna. Because the western boundary is adjacent to another forest sanctuary, the area represents one of the largest protected forests in Southeast Asia (Nakhasathien and Stewart-Cox 1990). The area falls between latitude 15° 00′-15° 50′ N and longitude 99° 00′-99° 19′ E. The topography is mountainous, ranging in elevation from 200 to 1,678 m.

The area is in the transition zone of tropical and subtropical climate. Year-round temperatures range from 6° to 38° C, averaging 24.4° C. November to April is the dry period. The mean annual rainfall is 1,552 mm, most of which falls from May to October.

Dominant forest communities are influenced by elevation, soil types, and geography, and include hill evergreen, moist evergreen in riparian habitats, dry evergreen, mixed deciduous, dry dipterocarp, and bamboo (e.g., *Bambusa* spp.)

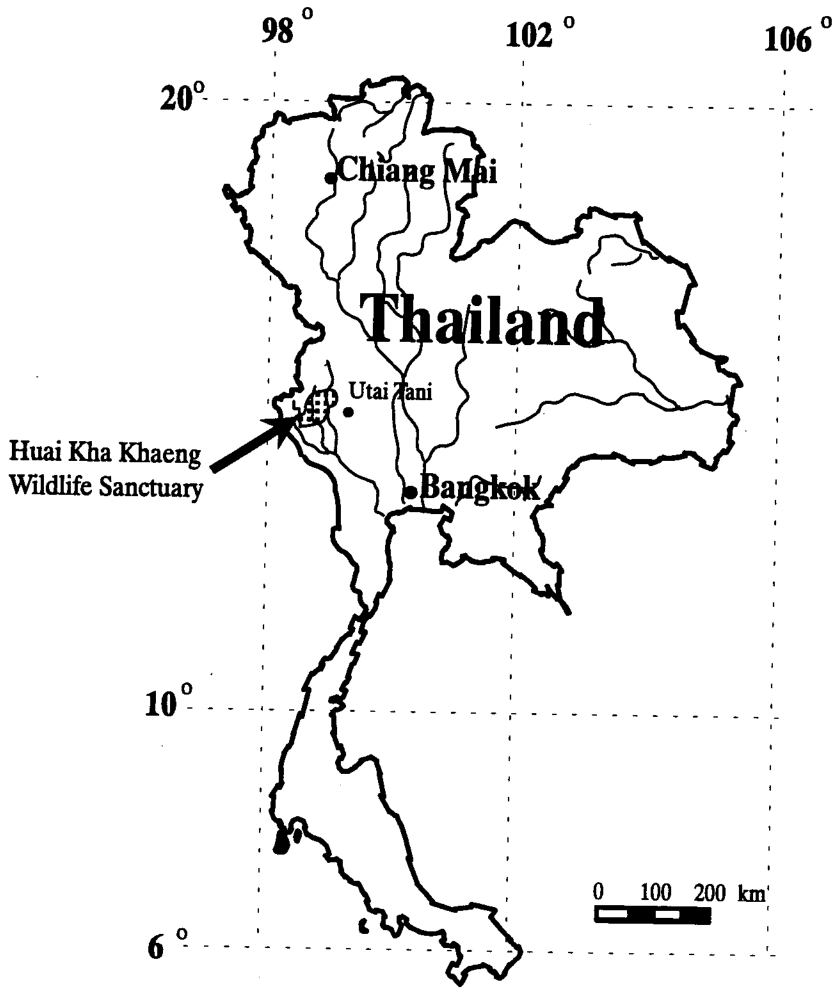

Figure 1. Location of Huai Kha Khaeng Wildlife Sanctuary in Utai Tani Province, western Thailand.

The mixed deciduous forest, in which most tree species shed their leaves during the dry season, covers about 1,171 km^2 of the HKKWS. Tree species are stratified into 2 canopy layers, overstory and lowerstory. Predominant species in the overstory are Lagerstroemia spp., Xylia kerrii, Afzelia xylocarpa, Vitex spp., Bombax anceps, Polyanthia asteriella, and Stereospermum neuranthum. The lowerstory is dominated by Cassia fistula, Croton spp., Cratoxylon spp., Lepisanthes tetraphylla, Sterculia spp., and Bauhinia variagata, interspersed with many bamboo species. The forest floor is occupied by various seedlings, shrubs, herbs, and grasses.

HKKWS has an unusual mix of fauna with Sundaic, Indo-Chinese, Indo-Burmese, and Sino-Himalayan affinities, many of whose ranges do not normally overlap (Nakhasathien and Stewart-Cox 1990). There are 68 species of mammals, 355 species of birds, 77 species of reptiles, and 29 species of amphibians; of these, 40 are threatened and 14 are endangered (Thailand Faculty of Forestry 1989). More than one-third of the wildlife species in HKKWS are thought to be cavity users (Nakhasathien and Stewart-Cox 1990). Twelve species of cavity-nesting birds are threatened and 1 species is endangered (Thailand Faculty of Forestry 1989).

The Huai Kha Khaeng watershed has been protected since 1972. More national forest areas were included in the sanctuary in 1986; these areas previously had logging concessions operating single-tree selection cutting (Thailand Faculty of Forestry 1989). This silvicultural system is practiced for sustainable yield. Only trees larger than size limits are marked for removal within the felling cycle of 30 years. Fifteen percent of the trees larger than the size limit, but less than 87.5 cm dbh are reserved, based on 4 conditions: good seed trees, solitary trees distributing seeds to surrounding areas, ridge trees distributing seeds along the slopes, and healthy trees expected to increase in timber value in the next rotation (Suprechakorn 1982:146-147).

METHODS

Stand Selection

I used topographic maps and site surveys to locate stands in the mixed deciduous forests. Five stands (replicates) each in unlogged and selectively logged areas were identified based on similarity of elevation, species composition, and accessibility.

Areas showing signs of forest destruction, such as old paddy fields, and areas in transition zones among mixed deciduous, dry dipterocarp, and moist and dry evergreen forests were not sampled. I used streams and hills to designate the boundaries of a stand. Unlogged stands were approximately 15 km from the unlogged stands.

Sampling Protocols

I used a quadrat technique to estimate trees and cavity densities. Using a species-area curve from a pilot study, I determined that 20- × 50-m plots adequately sampled tree species in the unlogged mixed deciduous forest type. I also used this plot size in logged stands.

From a randomly chosen starting position in each stand, I located a transect on a north-south or east-west bearing. I sampled 25 plots/stand located at random distances (25-50 m) and on alternate sides along each transect. In each plot, I measured dbh of all trees ≥20 cm dbh and examined each for cavities. I chose 20 cm dbh as a minimum tree size because preliminary examinations indicated that trees <20 cm dbh rarely had cavities. Cavities were defined as tree holes that had horizontal depths ≥7.5 cm (Gumtow-Farrior 1991) with entrances ≥3.0 cm wide. Trees with cavities were designated as cavity trees.

I assigned each tree to 1 of 3 diameter classes: small (20.0-39.9 cm dbh), medium (40.0-59.9 cm dbh), and large (≥60.0 cm dbh). I measured cavity tree height with a clinometer and placed each tree in 1 of 5 decay classes used as indexes of potential for cavity formation: (1) no dead limbs ≥5 cm in diameter, (2) 1 or 2 dead limbs ≥5 cm in diameter, (3) ≥3 dead limbs ≥5 cm in diameter, (4) portion of the tree trunk dead, and (5) tree dead (Carey and Healy 1981). Condition of the top (broken or intact) was recorded for cavity trees.

Cavity Correction Factors

I developed correction factors (Gysel 1961) for ground counts of cavities because some cavities cannot be seen from the ground and some tree holes can be miscounted as cavities (Gumtow-Farrior 1991). I randomly selected 120 trees from the most widespread cavity-producing taxa:

Lagerstroemia spp. (_n_ = 60), _Vitex_ spp. (_n_ = 30), and _Alangium salviifolium_ (_n_ = 30). Trees were climbed to 60-70% of their height using ropes and spurs following ground counts of cavities. I counted all holes that conformed with the cavity definition.

Statistical Analysis and Hypotheses Testing

I developed cavity correction factors for the dominant taxa, _Alangium salviifolium_, _Lagerstroemia_ spp., and _Vitex_ spp., using simple and multiple regressions. Log transformations of corrected cavity index and ground-count cavity data were used to develop the cavity corrected models for _Alangium salviifolium_ and _Lagerstroemia_ spp., because residuals of nontransformed variables indicated nonconstant variances.

I used stepwise multiple regression selection to identify the important variables related to number of cavities/cavity tree for all species combined and for the 3 dominant taxa.

I used _t_-tests to test the hypotheses that tree, cavity tree, and cavity densities were equal between unlogged and logged habitats for all species combined and for the dominant taxa. I also used _t_-tests to test the hypotheses that tree and cavity densities in each diameter class did not differ between unlogged and logged habitats and the hypotheses that dbh did not differ between noncavity trees and cavity trees for all species combined and for the dominant taxa.

RESULTS

A total of 3,142 trees of 91 species were sampled, 1,875 trees in unlogged stands and 1,267 in logged stands.

Cavity-forming Trees

Alangium salviifolium, *Lagerstroemia* spp., and *Vitex* spp. were the taxa that most commonly formed cavities in the mixed deciduous forest in HKKWS (Table 1). These dominant species accounted for 50% of the trees and 66% of the cavities in unlogged habitats.

Cavity Correction Factors

For each species, a strong relationship between ground counts and tree climbing counts allowed me to develop predictive equations (Table 2). Log transformations of corrected cavity index and ground-count cavity data were used for *Alangium salviifolium* and *Lagerstroemia* spp. because residuals of nontransformed variables indicated nonconstant variance. I forced each equation through the origin (i.e., no intercept), however, the intercept for *Lagerstroemia* spp. was significant (t = 2.84, 1 df, P < 0.0062). Tree dbh influenced estimates of corrected cavity indexes based on ground counts for *Lagerstroemia* spp. and

Table 1. Mean tree densities, cavities/tree, and cavity densities, and standard error (SE) for 10 dominant taxa in unlogged mixed deciduous forest in Huai Kha Khaeng Wildlife Sanctuary, Thailand, February to June 1992.

Species	Trees/ha		Cavities/tree		Cavities/ha	
	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE
Alangium salviifolium	34.43	3.72	2.83	0.21	105.59	8.55
Vitex spp.	38.57	1.64	2.21	0.18	81.22	16.44
Lagerstroemia spp.	52.81	7.47	1.54	0.09	81.85	16.83
Schleichera oleosa	25.17	1.98	0.96	0.20	23.21	8.84
Stereospermum neuranthum	20.31	1.36	1.07	0.23	17.9	7.36
Lepisanthes tetraphylla	27.37	3.30	0.64	0.12	16.85	3.82
Xylia kerrii	34.84	4.78	0.44	0.08	14.64	1.96
Terminalia nigrovenulosa	30.33	6.01	0.42	0.11	12.96	3.64
Cassia spp.	22.08	2.46	0.56	0.15	10.88	3.96
Fernandoa adenophylla	23.72	2.48	0.26	0.08	5.29	1.95

Table 2. Equations predicting total cavities from ground counts for the dominant taxa of trees in unlogged mixed deciduous forest in Huai Kha Khaeng Wildlife Sanctuary, Thailand, February to June 1992.

Species	Equation	R^2	*F*	*P*
Alangium salviifolium	LN(corrected cavity index) = (1.13)LN(ground-count cavities)	0.95	527.69	0.0001
Vitex spp.	Corrected cavity index = (0.78)(ground-count cavities) + (0.05)dbh	0.85	78.82	0.0001
Lagerstroemia spp.	LN(corrected cavity index) = (0.63)LN(ground-count cavities) + (0.01)dbh	0.90	266.54	0.0001

Vitex spp. (*t* = 5.42, 1 df, *P* < 0.0001; *t* = 2.72, 1 df, *P* < 0.0110, respectively), but did not influence estimates for *Alangium salviifolium* (*t* = 0.79, 1 df, *P* < 0.4477). I used these equations to correct cavity estimates for all additional analyses for these species.

Number of Cavities/Cavity-tree

Number of cavities/cavity-tree varied among species (Table 3), and was dependent on several variables. Height, dbh, condition of tops (intact or broken), and decay classes 2, 3, and 4 were associated with cavities/cavity-tree for all species combined. However, only dbh was associated with cavities/cavity-tree for the dominant species.

Dbh of Cavity and Noncavity Trees

Mean dbh for cavity trees for all species combined in unlogged stands ($\bar{x}$ = 46 cm, SE = 1) was greater (*t* = -7.56, 8 df, *P* < 0.0001) than that for noncavity trees ($\bar{x}$ = 34 cm, SE = 1). Mean dbh for cavity trees for *Alangium salviifolium* ($\bar{x}$ = 45 cm, SE = 3), *Lagerstroemia* spp. ($\bar{x}$ = 54 cm, SE = 4), and *Vitex* spp. ($\bar{x}$ = 47 cm, SE = 1) in unlogged stands was greater (*t* ≤ -3.42, 8 df, *P* < 0.0111) than for noncavity trees ($\bar{x}$ = 30 cm, SE = 3; $\bar{x}$ = 39, SE = 2; $\bar{x}$ = 34, SE = 2, respectively).

Table 3. Regression coefficients and *F*-statistics for variables related to number of cavities/cavity tree in all species combined, and the dominant taxa in the mixed deciduous forest in Huai Kha Khaeng Wildlife Sanctuary, Thailand, February to June 1992.

Variable	All species	*Alangium salviifolium*	*Vitex* spp.	*Lagerstroemia* spp.
Dbh	0.07[a]	0.12	0.11	0.07
	397.03[b]	47.55	240.67	677.24
	(0.0001)[c]	(0.0001)	(0.0001)	(0.0001)
Height	-0.09			
	56.44			
	(0.0001)	(>0.15)	(0.1131)	(>0.15)
Condition of tops	0.95		0.80	
	17.18		7.07	
	(0.0001)	(0.2281)	(0.0084)	(0.1049)
Decay class 1	(>0.15)	(>0.15)	(>0.15)	(>0.15)

Table 3. Continued.

Variable	All species	*Alangium salviifolium*	*Vitex* spp.	*Lagerstroemia* spp.
Decay	0.32			
class 2	4.45			
	(0.0350)	(>0.15)	(>0.15)	(>0.15)
Decay	1.38			
class 3	59.69			
	(0.0001)	(>0.15)	(0.1243)	(>0.15)
Decay	0.89			
class 4	17.40			
	(0.0001)	(>0.15)	(>0.15)	(>0.15)
Decay				
class 5	(>0.15)	(>0.15)	(>0.15)	(>0.15)

[a]Regression coefficients.

[b]*F*-value for partial R^2.

[c]*P*-value.

Tree Densities

Densities of trees ≥20 cm dbh and cavity tree densities differed between unlogged and logged habitats for all species combined. Mean density of trees in unlogged stands was 250 trees/ha (SE = 15) and was greater (t = 2.89, 8 df, $P < 0.0199$) than in logged stands ($\bar{x}$ = 169 trees/ha, SE = 24). However, mean densities of *Alangium salviifolium*, *Lagerstroemia* spp., and *Vitex* spp. did not differ ($t \leq 2.15$, df ≤ 8, $P < 0.0636$) between unlogged and logged stands.

Cavity trees comprised 45% of all trees ≥20 cm dbh in unlogged stands and 34% of all trees ≥20 cm dbh in logged stands. Mean density of cavity trees in unlogged stands was 121 trees/ha (SE = 13) and was greater (t = 4.27, 8 df, $P < 0.0027$) than in logged stands ($\bar{x}$ = 60 cavity trees/ha, SE = 6). Ninety-two percent of cavity trees were alive. Mean cavity tree densities for the dominant species did not differ ($t \leq 1.92$, df ≤ 8, $P \leq 0.3698$) for all species combined between unlogged and logged stands.

Both unlogged and logged stands had similar size distributions; there were 60%, 26%, and 14% of small, medium, and large trees, respectively, in unlogged and 60%, 25%, and 15% in logged stands. The mean density of trees for all species combined differed by size class between unlogged and logged stands (Fig. 2).

The density of Lagerstroemia spp. and Vitex spp., by size class, did not differ between unlogged and logged habitats. However, more small (t = 2.21, 6 df, P < 0.0009) and medium (t = 3.25, 5 df, P < 0.0167) Alangium salviifolium were found in unlogged than in logged stands (Fig. 3).

Cavity Densities

Mean cavity density for all species combined in unlogged stands ($\bar{x}$ = 407 cavities/ha, SE = 59) was greater (t = 3.59, 8 df, P < 0.0070) than in logged stands ($\bar{x}$ = 189 cavities/ha, SE = 15). Mean cavity density ($\bar{x}$ = 139 cavities/ha, SE = 12) for Alangium salviifolium in unlogged stands was greater (t = 4.44, 6 df, P < 0.0044) than in logged stands ($\bar{x}$ = 49 cavities/ha, SE = 16). However, cavity densities for Lagerstroemia spp. and Vitex spp. did not differ ($t \leq$ 1.48, 8 df, P < 0.1775) between unlogged and logged stands. Cavity densities differed ($t \geq$ 2.56, 8 df, P < 0.0335) by size class between unlogged and logged habitats (Fig. 4). Cavity densities did not differ ($t \leq$ 1.68, 8 df, P < 0.1317) by size class between unlogged and logged habitats for Lagerstroemia spp. and Vitex spp. More cavities (t = 2.63, 5 df, P < 0.0460) were found in medium-size *Alangium salviifolium* in unlogged stands than in logged stands (Fig. 5). However, cavity densities did not differ ($t \leq 2.29$, df ≤ 6, $P < 0.0613$) between logged and unlogged stands in small and large *Alangium salviifolium*.

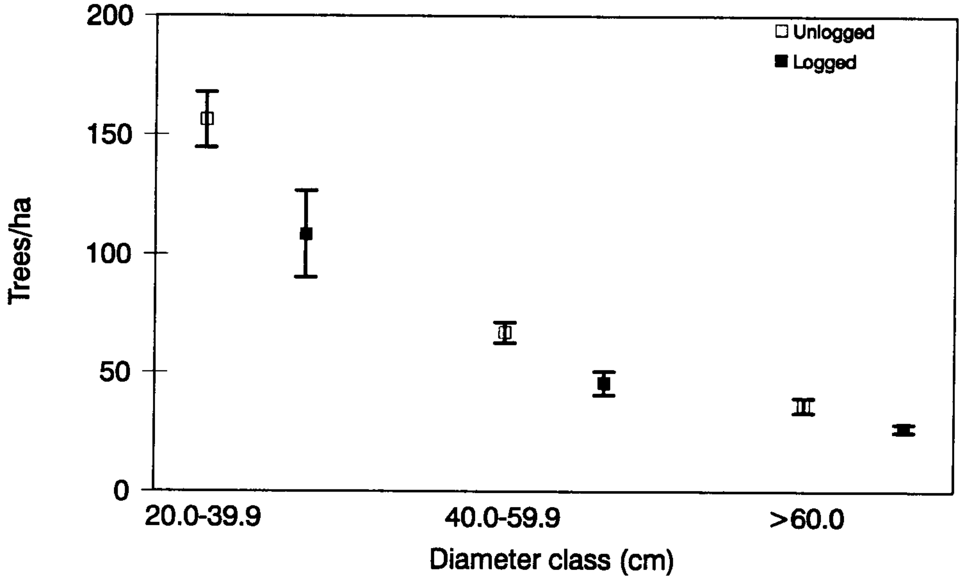

Figure 2. Mean tree densities and standard errors by diameter (dbh) class for all species combined in unlogged and logged mixed deciduous forests, Huai Kha Khaeng Wildlife Sanctuary, Thailand, February to June 1992.

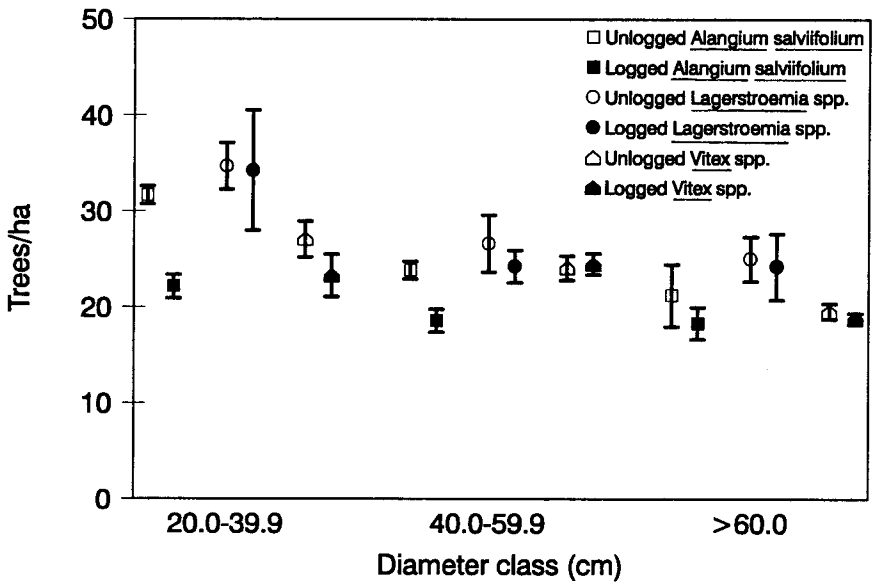

Figure 3. Mean tree densities and standard errors by diameter (dbh) class for the dominant taxa in unlogged and logged mixed deciduous forests, Huai Kha Khaeng Wildlife Sanctuary, Thailand, February to June 1992.

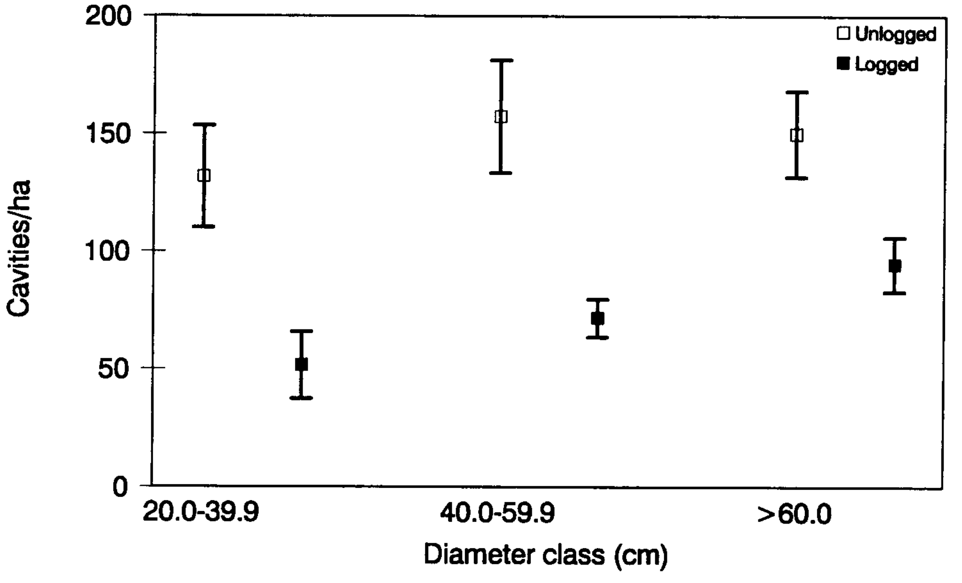

Figure 4. Mean cavity densities and standard errors by diameter (dbh) class for all tree species combined in unlogged and logged mixed deciduous forest, Huai Kha Khaeng Wildlife Sanctuary, Thailand, February to June 1992.

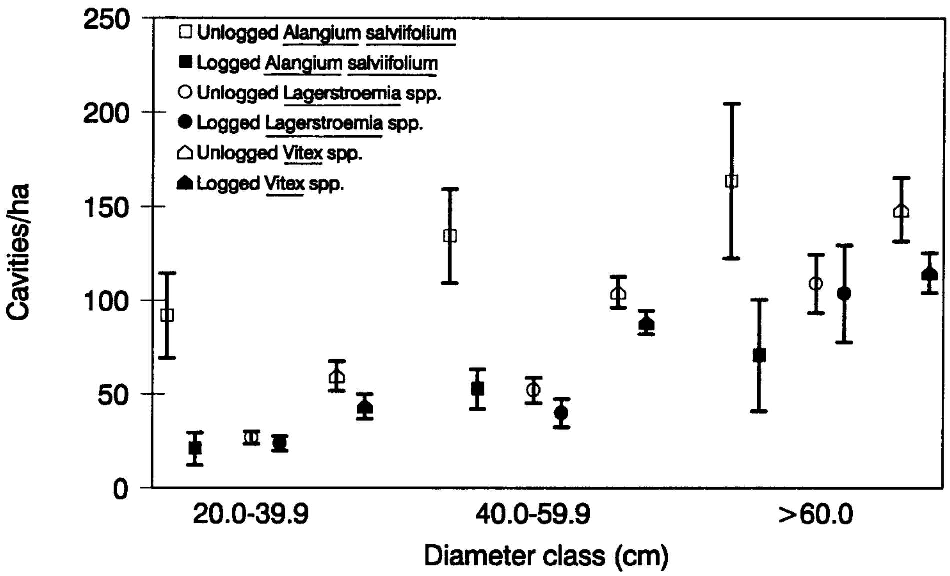

Figure 5. Mean cavity densities and standard errors by diameter (dbh) class for the dominant taxa in unlogged and logged mixed deciduous forests, Huai Kha Khaeng Wildlife Sanctuary, Thailand, February to June 1992.

DISCUSSION

The effects of logging mixed deciduous forest in Thailand on cavity abundance, and the factors related to the number of cavities in these forests are similar in many respects to forests of temperate North America. Logging generally reduces cavity availability, but will depend on the tree species and the silvicultural system used. The single-tree selection system used in the mixed deciduous forest in this study reduced cavity densities for all tree species combined because tree densities were reduced, particularly in the large size class. Unmanaged old-growth stands of the beech (Fagus spp.)-maple (Acer spp.) type forest in Michigan had more cavities, mostly in mature trees, than managed stands (Gysel 1961). Shortages of potential cavity nest sites may exist in all ages of intensively managed forests (Carey 1983). Although the single-tree selection reduced tree and snag densities in the mixed hardwoods and eastern hemlock (Tsuga canadensis) forests in Connecticut, cavity densities did not differ between unmanaged and managed stands (McComb and Noble 1980). Despite the reduction in cavity densities for all tree species in this study, cavity densities were not reduced for 2 of the dominant cavity-producing taxa.

Lagerstroemia spp. and Vitex spp. had similar cavity densities between unlogged and logged stands because these species had minor timber values, perhaps because of the existence of cavities, and probably were not marked for removal. However, these species are on the government timber list with minimum size limits of 48 cm dbh (Ministerial Regulation 1988).

The decline in cavity abundances may affect the cavity-user population in HKKWS. The number of holes determined the maximum number of nesting pairs of hole-nesters (von Haartman 1957). However, Waters et al. (1990) suggested that in habitats where timber management has not substantially reduced availability of natural cavities, managers should not assume nest site limitation, because they found that densities of secondary cavity-nesting birds did not decline after some cavities had been blocked.

Tree size and condition were important variables in determining cavity abundance in the mixed deciduous forests at HKKWS. Dbh was positively correlated with number of cavities/tree for each of the dominant species, and for all species combined. The relationship of cavity abundance to dbh in this study is probably a function of 2 factors, the aging process, and the preference that some cavity excavators show for large-diameter trees. As trees mature, they become more susceptible to disease and injury that in turn may facilitate cavity formation. Cavity development in the unmanaged beech-maple stands in Michigan occurred mainly in large and low-vigor trees (Gysel 1961). Cavity densities increased with increasing stand age in both pine and hardwood forest types in Florida and South Carolina (McComb et al. 1986b). Gumtow-Farrior (1991) found that cavities/tree increased with increasing dbh of Oregon oaks (Quercus garryana) and bigleaf maples (Acer macrophyllum). In Florida pine-hardwood forests, den trees were consistently larger in diameter than live trees without cavities (McComb et al. 1986a), and larger trees (>55 cm dbh) were preferred for cavity excavation in plains cottonwood (Populus sargentii) habitat (Sedgwick and Knopf 1986). Evans and Conner (1979) suggested that the height and dbh of nest trees tended to be normally distributed and that cavity nesters favored trees with dbh and height close to the mean. I found that trees with heights between 10-30 m (86% of all cavity trees) had a high potential for cavity formation. However, height was not an important factor in determining cavity abundance in the dominant taxa.

Most cavity trees (92%) in my study were live trees, which contrasts with many studies from temperate North America, where cavities were most abundant in dead or dying trees. Dead tree densities have been used as correlates of habitat quality for cavity nesters (Haapanen 1965, Balda 1975, Conner et al. 1975, Bull 1978, Evans and Conner 1979, Scott 1979, Thomas et al. 1979, Cunningham et al. 1980, Raphael and White 1984, McComb et al. 1986a, Morrison et al. 1986, Jimerson 1989). Annual ground fires, started by people living adjacent to the sanctuary, or by poachers, may be an important factor in eliminating dead trees from HKKWS. Almost the entire sanctuary is burned annually (Nakhasathien and Stewart-Cox 1990) and few dead trees remain following these fires. Although fires naturally occur in the mixed deciduous forest during the dry season, the natural fire frequency is unknown. Thus, it is not clear if human-caused fires substantially decrease the number of standing dead trees compared to the natural fire ecology of the area. Fire prescribed in southeastern Arizona ponderosa pine (Pinus ponderosa) forests to reduce accumulations of wood on the ground also reduced the number of standing dead trees (Horton and Mannan 1988).

Importance of live trees has been studied in temperate North America. Live cavity trees supplement cavities in snags and may remain standing longer than snags (Carey 1983). Scott et al. (1980) reported 42% of cavity nests in a quaking aspen (Populus tremuloides) community occurred in living parts of the trees. Up to 84% of all cavity trees in West Virginia's oak (Quercus spp.)-hickory (Carya spp.) forests were partially alive. Raphael and White (1984) found 19% of all cavity-nesting birds' nests in dead tops of live trees in California's old-growth pine (Pinus spp.)-fir (Abies spp.) forests. Sedgwick and Knopf (1986) and Carey (1983) suggested that in some unmanaged hardwood stands the dead and dying portions of live trees are probably more important to cavity-nesting birds than are dead trees or snags. Lawrence (1966) found that hairy woodpeckers (Picoides villosus) selected live trees for nesting. Given the current fire regime in HKKWS, live trees will continue to provide the majority of cavities within the sanctuary.

In my study, the relationship of decay class to cavity abundance varied among tree species. Decay classes 2, 3, and 4 were important factors for all species combined whereas decay classes 1 (trees with no dead limbs) and 5 (totally dead trees) were not. Baumgartner (1939) noted that the presence of large dead limbs was a good indicator of substrate potential for cavity formation in hardwood forest trees in Ohio. Sedgwick and Knopf (1986) found that, in plains cottonwood in Colorado, both total dead limb length and the number of trees with dead limbs were correlated with the number of cavities excavated. However, I found that decay class was not an important factor in the dominant taxa, and Carey (1983) reported that the number of dead branches was not a good indicator of cavities in an eastern mixed-species deciduous forest. Gumtow-Farrior (1991) reported similar findings for Oregon white oak forests.

The condition of the tree top (broken or intact) has been reported to be an important factor in cavity formation (McClelland and Frissel 1975, Scott et al. 1978, Runde and Capen 1987). However, I found that trees with intact tops had more cavities than trees with broken tops. This may be a function of low densities of broken-top trees. Only 3% of the trees I sampled had broken tops.

CONCLUSIONS

Selection cutting reduced tree and cavity abundance in the mixed deciduous forest in Thailand. Alangium salviifolium, Lagerstroemia spp., and Vitex spp. were taxa most likely to form cavities, and logging had no effects on tree densities of these species or on cavity densities in Lagerstroemia spp. and Vitex spp. However, cavity densities in Alangium salviifolium were reduced by logging. Dbh, height, condition of top (intact or broken), and decay classes 2, 3, and 4 were associated with cavity abundance for all species combined, but only dbh was associated with cavity abundance for the dominant taxa. Cavity trees were larger in dbh than noncavity trees for all species and for the dominant taxa. Most cavities were in live trees, which is probably a function of annual fires within the sanctuary that remove dead trees.

MANAGEMENT RECOMMENDATIONS

If logging resumes in mixed deciduous forests in Thailand, the effects of the selection cutting on cavity-dependent wildlife would be minimized by adopting the following guidelines: (1) logging of *Alangium salviifolium*, *Lagerstroemia* spp., and *Vitex* spp. should be minimized because of their high value as potential cavity-forming trees; and (2) at each entry, retain live trees of other species that have intact tops, dbh ≥40 cm, and ≥3 large dead limbs as long-term cavity resources.

Biologists should gather information on the effects of logging on cavity-dependent wildlife in all forest types. Quantitative information such as densities of animals, number of nesting cavities/year required, and sizes and species of cavity trees should by collected. Information on threatened and endangered species should be the first priority. Such information could be used to develop guidelines for minimizing logging impacts on cavity-dependent wildlife in decision making in the future when logging resumes. Finally, the effects of annual fires on the ecology of all forest types in HKKWS should be examined.

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APPENDIX

APPENDIX 1. Species found using tree cavities in mixed deciduous forests, Huai Kha Khaeng Wildlife Sanctuary, Utai Tani Province, Thailand, February to June 1992.

Common name	Scientific name
Birds	
Collared falconet	Microhierax caerulescens
Red-breasted parakeet	Psittacula alexandri
Vernal hanging parrot	Loriculus vernalis
Indian roller	Coracias benghalensis
Hoopoe	Upupa epops
Brown hornbill	Ptilolaemus tickelli
Oriental pied hornbill	Anthracoceros albirostris
Lineated barbet	Megalaima lineata
Green-eared barbet	M. faiosatricta
Coppersmith barbet	M. haemacaphala
Common flameback woodpecker	Dinopium javanense
Laced woodpecker	Picus vittatus
Lesser yellow-naped woodpecker	Picus chlorolophus

APPENDIX 1. continued

Common name	Scientific name
Great slaty woodpecker	Mulleripicus pulverulentus
White-bellied woodpecker	Dryocopus javensis
Velvet-fronted nuthatch	Sitta frontalis
Hill myna	Gracula religiosa
Reptiles	
Tokay gecko	Gekko gecko
Orange-winged flying lizard	Draco maculatus
Yellow tree monitor	Varanus bengalensis
Reticulated python	Python reticulatus

Scientific nomenclature for birds is from Lekagul and Round (1991), and for reptiles, Nakhasathien and Stewart-Cox (1990).